A new QRA model for rail transportation of hazardous goods

Charlotte Bouissou, Emmanuel Ruffin, Raphaël Defert, Franck Prats, Eric Dannin

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BOUISSOU Charlotte, RUFFIN Emmanuel**, DEFERT Raphaël, PRATS Franck, DANNIN Eric***,
Engineers - Safety in Transportation System - **Program manager for Tunnel Safety and
Transportation of Hazardous Goods - ***Technician - Software developments
Contact : charlotte.bouissou@ineris.fr
Institut National de l'Environnement Industriel et des Risques (INERIS),
Parc Technologique Alata, F-60550 Verneuil-en-Halatte, FRANCE, www.ineris.fr
Tel : (33) 3 44 55 65 92 - Fax : (33) 3 44 55 62 95

1. Context

Balancing the different way to transport goods is one of the European Union wills expressed in the « white paper » of transportation [1]. This new view leads to consider the railway mode, in order to choose the less risky route for the transportation of goods, these routes being able to combine several means of transports by road or rail. For this objective, it then appears important to be able to assess and compare the risks related to hazardous goods transportation.

The aim of this paper is to show the INERIS research project funded by the French Ministry of Ecology and Sustainable Growth and by the French Ministry of Equipment, Transportation and Buildings[2]. This project is related to the assessment of the risk induced by the transportation of hazardous goods by road, by rail and by the combined means of transportation. The main target of this project is to develop a "multi-modal" quantitative risk assessment model (QRAM).

A QRA Model applicable to the road transportation already exists. Within the framework of a research project carried out for both the OECD and the PIARC (World Road Association) INERIS with WS-Atkins and the Institute of Risk Research (University of Waterloo) has already produced such a model. For two years, this tool is recommended in the French regulation and used to realise comparative risk studies for roads including tunnels, crossing more or less populated areas, with a more or less dense traffic [7].

2. QRA Model

The main purpose of the QRA model is to assess the risks relative to the transport of Dangerous Goods in a quantitative way. The model evaluates simultaneously the consequences and the frequencies of occurrence of possible scenarios. This makes it possible to assess quantitatively the societal risk (if the distribution of the people liable to be exposed is at hand) and the individual risk.

A complete assessment of the risks due to Dangerous Goods would require to consider all the possible weather situations, all kinds of accidents with all types of vehicle partially or fully loaded, etc. Such an evaluation is completely impossible and some simplifications have to be introduced. The QRA model is based on the following steps:

- Choice of a restricted number of Dangerous Goods.
- Choice of some representative accidental scenarios implying those Dangerous Goods with their usual packagings.
- Identification of physical effects of those scenarios for an open air or a tunnel section.
- Evaluation of their physiological effects on road or rail users and local population.
- Taking into account of the possibilities of escape/sheltering.
- Determination of the yearly frequency of occurrence for each scenario.

F/N curves and their expected values are the major outputs of the QRA model. They are defined as follows:

Frequencies / Gravity curves (F/N curves): stand for the annual frequency of occurrence F to have a scenario likely to cause an effect (generally, the number of fatalities) equal to or higher than N.

Expected value (EV): number of fatalities per year, obtained by integration of a F/N curve.

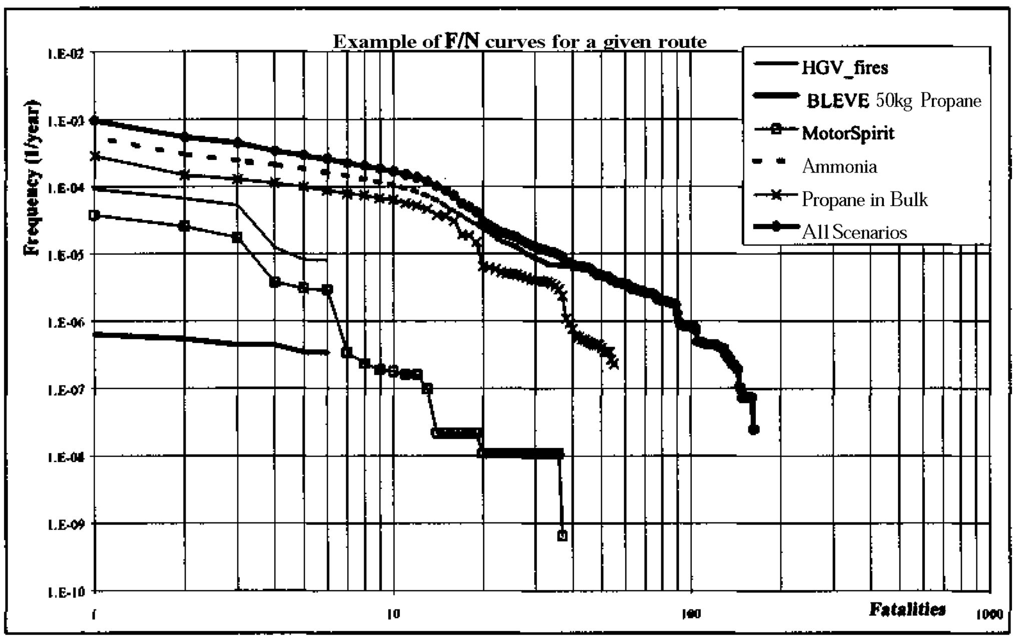

Figure 1: Example ofFN curve

Detailed descriptions of the road model, which is based on the same general methodology, are given in the reference [4,5,6] .

3. Rail transport in the EU

3.1 The situation concerning the rail transport of hazardous goods in the EU

The general regulation of the rail transportation of dangerous goods is based on the Directive 96/35/EC of 3 June 1996 on the appointment and vocational qualification of safety advisers for the transportation of dangerous goods by road, rail and inland waterway and the Directive 96/49/EC of 23 July 1996, and its amendments, on the approximation of the laws of the Member States with regard to the transport of dangerous goods by rail. The latter directive leads to apply the regulation for international transport of dangerous goods by rail (RID) within and across the Member States (Article 1). Thus the RID constitutes the annex of this directive and the main recommendations concern the following parts:

Part 1 - General requirements,

Part 2 - Special requirements relating to the various classes,

Part 3 - Appendices (miscellaneous requirements about goods, recipients, tests...)

In these two directives there is no general recommendations about the transit of dangerous goods through tunnels.

Such regulations/recommendations are treated in the following documents:

Commission Decision 2002/732/EC of 30 May 2002 concerning the Technical Specification for Interoperability (TSI) relating to the infrastructure subsystem of the trans-European high speed rail system referred to in Article 6(1) of Council Directive 96/48/EC. In fact these TSI are not specific to dangerous goods but related to the fire events. The specifications mainly concern the limitation of the generation, the propagation and the effects of fire and smoke in the event of fire [2],

— **UNECE** (draft recommendations 30 July 2003) "Report of the Ad Hoc **Multidisciplinary** group of experts on safely in tunnels (rail) on its fourth session",

— **UIC** leaflet 779 - 9 on Safety in Railway Tunnels which has been taken into account for the elaboration of the UNECE document,

— CEN prEN 45545 related to fire resistance for railway passenger wagons (no specific indications about dangerous goods),

Thus the UNECE and UIC documents appear to be the most specific documents on rail tunnel safety but they are not enforced at the law level. At law level **TSIs** concerning the infrastructure subsystem give the minimum safety requirements for rail tunnels within the scope of the interoperability purpose and only for the fire **events.**

It is also important to note that the causes of DG accident is depending at a primary step on railway incidents and thus the Directives 96/48/EC, **2001/16/EC** giving TSIs as well as the Project Directive relative to the Safety of European Railways setting up the Common Safety Objectives, Methods and Indicators (CSO, CSM, **CSI)** might to be considered.

All these documents related to safety in rail tunnels or for the transport of dangerous goods by rail thus appear to be, a complex set of references, hard to use efficiently and not sufficiently harmonised with the road mode.

3.2 The Situation in the Professional Engineering World for Rail mode

Compared to the road mode the question of the dangerous goods transport **(DGT)** by rail is following a quite different regulation scheme mainly based on prescriptions.

The main prescriptions relative to the transport of dangerous goods through rail tunnels are included in the following documents:

- UNECE - R **C1-10** (only for new tunnels),

Invoke the possibility for the high-risk tunnel and if operating conditions permit to segregate trains carrying dangerous goods in bulk from passenger trains,
The trains driver have to know information about DGs carried when going through a tunnel and the operator must be able to pass information on the carried DGs to fire brigades,
Risk analysis of safety measures involving DGs are based on cost-benefit considerations of various options, for example **freigth** train carrying DGs are diverted on routes without tunnels or diverted on routes without dense populated **area...**

— UNECE - S **C4-15** (only for new tunnels),

"*... operating company should normally provide such information (train consist) to the network operator before the departure of the train carrying dangerous goods.* "
Within the UNECE prescription (draft document) we can notice that there is no specific recommendation or standard indicated for DGs through existing rail tunnels. But a global recommendation to raise the safety level is made if possible with no-structural measures in order to limit the cost. The use of QRA approaches and performance objectives appears to be the better way to raise the safety level for existing tunnels by optimising the operation of the rail network.

Also in the framework of the present regulations the Directive **96/49/EC** suggests that for some safety aspects not treated in the RID Member States can propose specific safety measures (Article **1.2).** These points are the following:

— the traffic trains planning,

— the order of the wagons in a train for intra-State transport,

— the operation safety rules for the nodes of the rail transport system such as marshalling yards or parking,

— the operators staff training and the management of information related to dangerous goods,

— the specific rules concerning the transport of some dangerous goods in passengers trains.

The Article 6.11 should also lead Member States to make use of the QRA approaches for the rail mode in order to define specific safety rules for regular local transport of dangerous goods from a given industry site and on a given well-defined route. Thus, the application of this article also implicitly entails the identification of the less risky route.

Reaching the appropriate balance in the different modes in use for the transport of goods is also one of the European Union strong wills expressed in the « white book » of transportation. This new view leads to consider the railway mode as well as the road mode, in order to choose the less risky route for the transportation of goods. Moreover, whereas in some cases alternative route can result in a combination of various modes. For this objective, it then appears important to be able to assess and compare the risks related to hazardous goods transportation even though the perception of the "common" accidental risks is not often is relation with dangerous good transportation concerns.

Nevertheless reasonable assessment of the risks involved by the dangerous goods has be to taken into account properly in the overall decision making process for upgrading or building railway infrastructures taking into account the interactions with the road network.

Thus in the same way as for the risk assessment process pertaining to the road transportation mode, making use of the QRA approach could lead to a better management of global risks pertaining to DGs in complement to the RID prescriptive approach.

4. QRA rail model

4.1 General approach

Even though the present regulation does not recommend QRA models for the rail mode some objectives are more or less related to the QRA application and should involve this kind of model in the near future. Considering a such possibility INERIS has developed a model for rail transportation of DGs. This new model has been developed taking into account the same global philosophy on which the road OECD/PIARC model was based. By this way road and rail models produce homogeneous assessment and then allow the study of multi-modal transport systems.

The long-term principles of a global assessment of risks on multi-modal routes can schematically be drawn as shown in Figure 2.

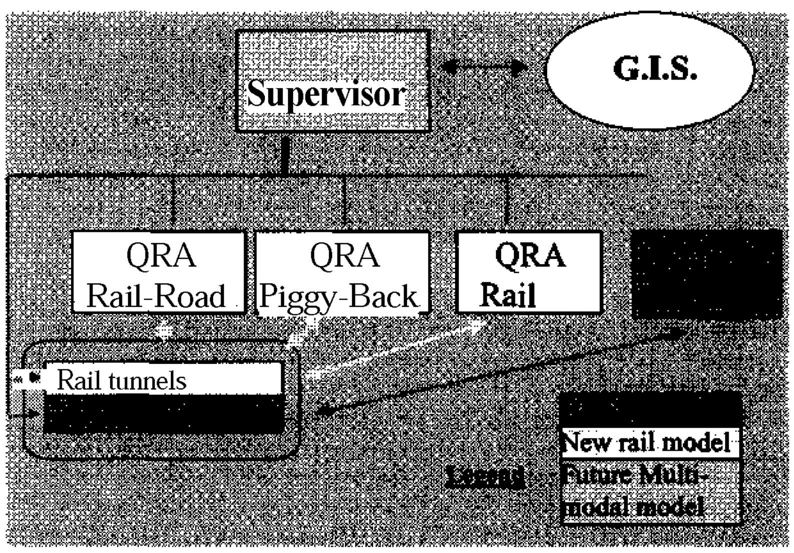

Figure 2: Principle diagram for the Multi-modal plate-form for DGs risks assessment.

During the development, two points stayed in mind: homogeneity with the "road tool" and specificity of rail transportation. Risk assessment, level of details, global approach have to be similar for both mode to allow comparison between modes. Therefore, the philosophy of the "road tool" has been kept. This philosophy is based on a choice of a limited number of hazardous good, a choice of a limited number of scenarios, assessment of probability and assessment of physical and physiological effects. However, capacities engaged, accident progress, traffic are different in the two modes. These differences have been assessed with a systemic approach of the railway mode. Especially frequencies of accident scenarios take into account the probability of incident weighted by conditional probabilities to reach a major accident implying hazardous goods. The frequencies are also connected to the local properties of the line environment and to the type of operating system.

The rail QRA model was elaborated using an approach similar to the one used for the road QRA model. But it will require the development of new "sub- modules", specific to the railway routes. On certain aspects, a direct adaptation from the Road QRA model is not possible. For instance road traffic, constituted by a large number of vehicles may be described as continuous. On the other hand, rail traffic constituted by trains appears as essentially discontinuous.

4.1 Choice of scenario

The numbers of scenarios and of Dangerous Goods involved had to be very restricted for simplification and applicability purpose. Scenarios had to be in accordance with scenarios in the road model and had to be representative of Dangerous Goods Transport by rail. This challenge was met with a panel of 10 scenarios that have been developed for each mode in the QRA and are listed below

Scenario Nr:	Description	Road/ Intermodal/ Rail-Road	Rail
1	Fire 1	20 MW	30 MW
2	Fire 2	100 MW	130 MW
3	BLEVE of LPG in cylinder	50 kg	-
4	Motor spirit pool fire	28 tons	65 tons
5	VCE of motor spirit	28 tons	65 tons
6	Chlorine release	20 tons	65 tons
7	BLEVE of LPG in bulk	18 tons	51 tons
8	VCE of LPG in bulk	18 tons	51 tons
9	Torch fire of LPG in bulk	18 tons	51 tons
10	Ammonia release	20 tons	58 tons

Figure 3: Scenario chosen for rail QRA model

4.2 Type of accident considered

Only accidents involving a transport of hazardous material are considered. Learning from experience was used to see what type of accidents can occur and what were the cause and the consequences. These approaches were completed with a basic study of the rail system. As one can suppose, these accidents are essentially derailments or collisions.

For road accidents, HG transports are in the continuous flow of vehicles including passenger vehicles so passengers are always involved in the accident. Each accident could be treated in the same way, considering that the accident will produce a traffic jam growing proportionally to the traffic flow.

For rail accidents, in most case only one or two trains are involved and that will be the only cases considered. Passenger trains can be present or not. Treatment, particularly evaluation of gravity, will be different in both cases.

For each accident that can occur involving HG, frequency and gravity have been evaluated. All results are aggregated in a FN curve.

4.3 Evaluation of frequency

As mentioned before, the study was funded by the French ministry of transport, indeed French database of accidents involving hazardous material was used. Hopefully, they're only few accidents that make difficult to be significant and exhaustive. Therefore generic accidents involving all types of trains have been taken into account. For all kind of accident: collision, derailment, a frequency has been estimated. Next the ratio of trains transporting HG and a probability to have a failure has been introduced.

According to the grade of sensibility wondered in the study and data available, two methods were developed, a global one and a method that take into account local environment particularities of the railway lines that induce risk as exploitation specificity called **'contextual method'.**

On one hand, the global method will be used in case of poor knowledge of the data or for a global evaluation, the **frequency** of accidents will be the same all the route long. On the other hand, the contextual method is based on the definition of contexts with specific rate of collisions and derailments. Four families of contexts were chosen: type of track as double track, type of exploitation, type of environment as bridge or tunnel and specific risk as malicious intent. The contextual method can be use only if data can be put behind each kind of context defined previously.

The overall risk assessment can rely on the establishment of a typical (simplified below) scenario tree considering a major rail accident involving dangerous goods.

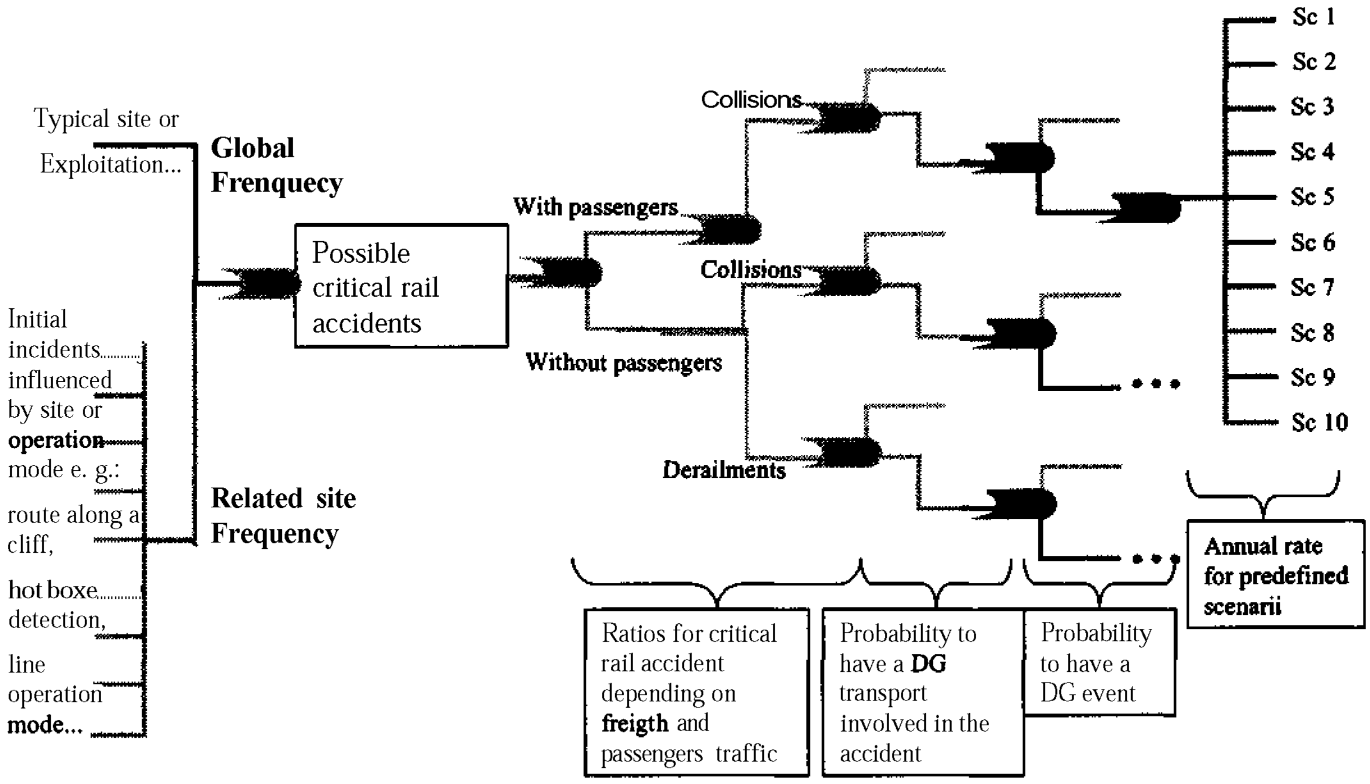

Figure 4 : Simplified scenario tree governing the new QRA-rail model

4.4 Evaluation of gravity

In both models, only victims due to HG are considered, victims of circulation accidents are not taking into account. Victims, dead or injured in the local population and victim in the eventually passengers trains involved are studied separately.

In the open air, consequences of physical phenomena are calculated by existing dedicated models. Consequences are calculated using percentages of lethality and/or injuries, using probit equations (Equation which allows to deduct the physiological consequences from the exposure to physical consequences of a phenomenon) and considering the possibility to escape or to get shelter.

Usually, open-air models calculating consequences of scenarios can not be used in tunnels and a specific development has been made to determinate:

- The tunnel zones which can be affected by the scenario,
- Effects that can overflow out of the tunnel and which can generate effects in the open air outside the tunnel.

The complexity of problems to deal with and the number of possibilities of equipment and ventilation system (longitudinal, transversal or semi-transversal ventilation, one or two tubes...) in the tunnels lead to use simplifications.

The model used in the road tool developed with the collaboration of WSAtkins, UK, is an independent module and can be used separately. It was modified to considered rail scenario and rail tunnel specificity as piston effect induced by train's stop in the tunnel.

5. Conclusion

Present developments will broaden the possibilities and the scope of the already existing road QRA model. In the fields of Risk Assessment relative to the Dangerous Goods transport, comparisons between different routes and means of transport will become possible.

Furthermore, one have to keep in mind that Risks are an important component of the transport development in Europe and that a local regulations of DGs transit or requests can influence significantly long travel.. In that way, QRA Models developed can estimate the influence of various modes on various routes. So, it would be interesting to introduce this parameter on the level of the management of European transport in the future. Of course, the parameters of risks are not the only important ones and of the multi-criteria approaches that would put in parallel risk assessment but also the economic impacts, the society profits and a better management of the costs of transport would be extremely useful.

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